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THE KILAUEA VOLCANO OBSERVATORY

BY A COMMITTEE OF THE NATIONAL ACADEMY OF SCIENCES

PREPARED AT THE REQUEST OF THE SECRETARY OF AGRICULTURE

Communicated by C. D. Walcott, October 8, 1920

February 11, 1920.

DR. CHARLES D. WALCOTT, *President*,
The National Academy of Sciences.

DEAR SIR:

The Committee appointed by you to respond to a request from the Secretary of Agriculture for the advice of the National Academy of Sciences in regard to the conduct, by the Weather Bureau, of the Kilauea Volcano Observatory on the island of Hawaii, submits the following report. This Committee consists of Whitman Cross, Chairman, William Bowie, Arthur L. Day, Herbert E. Gregory, and Harry Fielding Reid. The letter of the Secretary of Agriculture indicating the scope of the subject on which the assistance of the Academy is desired is as follows:

DEPARTMENT OF AGRICULTURE, WASHINGTON,
January 18, 1919.

DR. CHARLES D. WALCOTT, *President*,
National Academy of Sciences,
Washington, D. C.

DEAR DOCTOR WALCOTT:

May I not request the National Academy of Sciences to give the Department the benefit of its advice with reference to scientific questions involved in the conduct of investigations in seismology and volcanology, to be carried on principally at the Kilauea Volcano, Hawaii, and elsewhere as the circumstances may warrant? The Congress, at its last session, appropriated \$10,000 for this purpose, and it apparently had in mind the transfer to Government support and direction of the investigations now under way at this volcano, under the supervision of Dr. T. A. Jaggar, which are supported by the Hawaiian Volcano Research Association. The Department, through the Weather Bureau, desires to inaugurate the work promptly and efficiently and to secure the best contributions to the science of volcanic and seismic actions that may be possible within the limited appropriation available. If the representatives of the Academy of Sciences designated to consider this problem desire further details relative to the questions involved, the Chief of the Weather Bureau will be very glad to coöperate with them in every feasible way. I shall appreciate it if you will give the matter your early and favorable consideration.

Very truly yours,

D. F. HOUSTON, *Secretary*.

Soon after the appointment of the Committee it secured from Prof. C. F. Marvin, Chief of the Weather Bureau, a full statement in regard to the work of the Kilauea Observatory and the circumstances of its transfer from the Hawaiian Volcano Research Association. The Committee is much indebted to Professor Marvin for his cordial coöperation at all times.

The request of the Secretary of Agriculture pertains on the one hand to the immediate conduct of the Kilauea Observatory under existing appropriations, and on the other to the general subject of investigations in seismology and volcanology under the auspices of the Weather Bureau which may be conducted elsewhere than at Kilauea if circumstances warrant. As prompt action was desirable regarding the observatory, while the broader subject required further consideration, the Committee submitted to you under date of February 12, 1919, a preliminary report with recommendation as follows:

The Committee recognizes the importance of the work hitherto accomplished at the Kilauea Observatory under the auspices of the Hawaiian Volcano Research Association and the direction of Dr. T. A. Jaggar, Jr. It also recognizes the great importance of maintaining continuity in the observations and records of the Observatory. This continuity appears to be endangered and the Committee earnestly recommends that the Department of Agriculture, through the Weather Bureau, should immediately take control of the Hawaiian Volcano Research Association equipment and provide for the uninterrupted continuance of the present program of observations and records until opportunity has been given for a thorough study of the opportunities for research in volcanism and seismology in this and adjacent regions, and the possible agencies through which a concordant and effective program can be carried out. The agreement already reached between the Department and the Hawaiian Volcano Research Association appears to furnish an appropriate basis upon which the Weather Bureau can assume control of the Kilauea Observatory.

The broad request of the Secretary of Agriculture for advice as to the scientific problems involved in the conduct of the work in question, in order to secure the best results possible under the available appropriation by Congress, requires more mature consideration on the part of the Committee. It will give careful attention to this matter and submit its full report as soon as possible.

This report was transmitted by you to the Secretary of Agriculture, and in accordance with its recommendation the control of the Kilauea Observatory was at once assumed by the Weather Bureau and has been maintained under the general plan of its earlier administration. The Committee now presents its complete report and recommendation on the subjects outlined in the Secretary's letter to you, giving particular attention to the broader aspects of researches in seismology and volcanology and the larger agencies devoted to promoting them.

I. *Scientific Questions Involved in the Conduct of Investigations in Seismology and Volcanology.*—Seismology is the science of the causes and effects of earthquakes and the phenomena of their occurrence. Volcanology deals with the causes and phenomena of volcanic action and the character of the volcano itself. Both sciences treat phenomena arising from disturbances of more or less deep-seated origin in the lithosphere of the earth and are fundamentally branches of physical geology. Both belong to the group of the earth sciences, all of which are more or less intimately connected.

In seismology the immediate subject of investigation is the shock, heavy or light, which is transmitted from its sources through rocks to

the place of observation on the earth's surface. The propagation of this wave-like movement is a matter for physical and mathematical discussion but the shock must also be studied in regard to its origin, the geological conditions under which it arises, the character of the material through which it is transmitted, and the conditions under which divers catastrophic phenomena may be exhibited at the surface.

Nearly all earthquake shocks are known to be due to relief or strain in the rocks of the earth at various depths below the surface. Such relief sometimes occurs in fault zones in the rocks where the geologist has recognized that movements have also taken place in past epochs. Other earthquakes are associated with volcanic disturbances. The source of many earth tremors cannot at present be determined.

Volcanology deals most directly with the physical and chemical phenomena of activity at the vent. However, a volcano represents but one local, though important, phase of eruptive activity. Its lavas are often but a small part of the igneous matter involved in the movement, other portions consolidating beneath the surface or pouring out from fissures as lava floods which may not be demonstrably connected with a typical volcanic centre. Volcanoes are of many types of activity dependent upon the chemical character of the magma involved, including the associated gases, and on differing physical conditions. A volcano is a natural laboratory where the geologists, physicists, chemists, mineralogists, petrographers, seismologists, and other specialists have a most important opportunity to study a great many processes in operation which have been active during the entire history of the earth from the time of its oldest known rocks. The geologist is vitally interested in volcanic phenomena as he is in all current processes whose effects are visible, though perhaps not clearly comprehensible, in the older rocks. The study of extinct and more or less deeply dissected volcanoes of past ages and the theoretical discussions of igneous earth history point to various phases of volcanic activity as of particular importance. This information has an important bearing on the plan of investigation to be carried out at a volcano observatory.

The consideration of physical processes in special relation to the development of the earth is now commonly called geophysics. By analogy we may also recognize geochemistry. Volcanology is sometimes referred to as a branch of geophysics but it clearly bears an equally intimate relation to geochemistry. The prolonged physical and chemical processes of volcanism result, on the material side, in volcanic rocks, minerals, and the volcano itself. No scheme of volcanological research is complete which does not provide for supplementing the field observations by studies in physical, chemical, and petrological laboratories.

This brief and imperfect summary of the scope and relations of seismology and volcanology is designed to show that the "scientific problems

involved in the conduct of investigations" in these fields are many and complex. The coöperation of geologists, physicists, chemists, geodesists, and other specialists with volcanologists and seismologists is necessary both in constructing a plan for such research and in carrying it out.

In the abstract it is plain, we believe, that a general scheme of investigation in either seismology or volcanology is distinctly beyond the proper scope of the Weather Bureau's activities. This Committee cannot recommend that the Weather Bureau should organize special departments of research in these sciences. But there are conditions at the present time which make it both appropriate and fortunate that the Weather Bureau should assume the conduct of observation at the Kilauea Observatory. These modifying conditions will now be reviewed.

From the beginning of human history earthquakes and volcanic eruptions with their associated tidal waves have been perhaps the most awe-inspiring and terribly devastating manifestations of natural forces. They have occurred at irregular intervals, unexpectedly as a rule, and in widely separated parts of the world. Owing to long prevailing ignorance or crude ideas as to the causes of these phenomena, and to the difficulties in the way of making extended scientific observations concerning them, the sciences of seismology and volcanology are still in a poorly developed state. Science is as yet unable to predict where or when the next great catastrophic exhibition of either earthquake or volcanic activity may be experienced. Our present knowledge is sufficient, however, to show that, as our understanding of the source, the cause, and the nature of these phenomena increases, we shall gain in some measure a power to anticipate violent earthquakes and volcanic eruptions and to guard more and more successfully against their destructive and terrifying results.

It is essential to the future advance of seismology and volcanology that provision should be made to secure extensive and accurate observations and record of the phenomena involved. Studies of this kind must be carried on at the most favorable centres for such work, and according to plans of investigation representing the best information of the time. The extent and complexity of the work requires that it should be under the direction of an organization planned for the purpose. As the earthquakes or volcanic eruptions of to-day may be in the United States, Italy and Japan, those of to-morrow in New Zealand, Africa, or Iceland, and equally scattered at other times, it is plain that the researches in various countries, whatever their auspices, should be conducted on the same general plan, and that a world-wide correlation of data and coöperation in effort is of the greatest importance. In the closing paragraphs of this report is a statement of the reorganization now in progress, of international agencies intended to promote such coöperation.

The development of delicate automatic registering instruments for measuring the intensity and periodicity of earth tremors and analyzing

these complex motions into several components, has now progressed so far that a number of recording seismologic stations have been established in the United States by various government bureaus, in educational institutions and in private laboratories. In order that the records of such stations should be of much real value it is necessary, however, that certain conditions should be met. The sites must be selected with good judgment, the instruments should be of the best type, their installation must be satisfactory, and they must be in charge of skilled observers. Further, the efficiency of the seismologic stations in this country would be increased if they were under the supervision of a central coordinating organization. Such an organization does not exist, as yet. It would require, moreover, large financial support to establish the desirable number of special seismologic stations, with observers and adequate equipment, at all desirable points. The stations of the Weather Bureau are widely distributed, at many of them are trained observers capable of caring for seismometers and allied instruments, and it is, therefore, fortunate that Congress has for several years past appropriated a small sum of money which the Weather Bureau is authorized to spend in seismologic work.

It is the opinion of this Committee that, until a permanent special organization is created, the seismologic investigations of the Weather Bureau should be extended by the equipment of additional selected meteorologic stations, with the proper seismometers and other necessary instruments, to be operated by the staff of the Weather Bureau. The Committee, however, believes that the seismologic research of the Weather Bureau, if thus expanded, should be placed under the immediate direction of a trained seismologist, belonging to its corps. If this is inexpedient, it is suggested that the desirable supervision and advice might be secured by coöperation with the American Geophysical Union, connected with the National Research Council. It is to be noted that the Chief of the Weather Bureau and several of its staff are members of this Union, which includes also several of the leading seismologists of the country.

II. *Investigations in Volcanology and Seismology by the Weather Bureau in the Hawaiian Islands.*—Bearing in mind the general considerations as to researches in seismology and volcanology presented in the earlier part of this report, the Committee has reviewed the exceptionally favorable opportunity for obtaining valuable contributions to these sciences in Hawaii through the administration of the Kilauea Volcano Observatory and other studies of volcanic action by the Weather Bureau. The broader relations of such investigations have been considered. It is evident that the supervision of this work should be directed with due regard to general, provincial, and local relations which may now be discussed.

Observations and researches in volcanology and seismology carried

out at the Kilauea or any corresponding observatory cannot have their maximum value unless conducted with due appreciation of the more pressing problems requiring solution at the present time and of the work being done in other parts of the world to advance these earth sciences. Upon this basis the work in Hawaii can be most effectively directed, undesirable duplication avoided, and possibilities of fruitful coöperation recognized.

The Hawaiian Islands are one of many elongated groups or chains of volcanic islands scattered through the great Pacific Ocean basin. These islands have all been built up from considerable, and in some cases from great, depths, and some rise to notable heights above the sea. The Hawaiian chain really extends from the island of Hawaii for 1,500 miles to the west northwest far beyond the largest and best-known members of the group. The only active vents of the present time are the volcanoes of Mauna Loa and Kilauea on the island of Hawaii, but minor eruptions have occurred in geologically recent time on all of the principal islands, while submarine disturbances have been noted on the southeast of Hawaii which are supposed to indicate the existence of other vents where new volcanic mountains are being built up.

Kilauea and Mauna Loa are typical volcanoes of the sort formed by repeated eruptions of basaltic lavas, similar to those which have been predominant in the principal eruptions throughout the group and in most other islands of the Pacific Ocean basin. Kilauea, being one of the most frequently active volcanoes in the world, readily accessible, and presenting unusually favorable conditions for study, was naturally chosen as the site of an observatory of volcanic phenomena by the Hawaiian Volcano Research Association, formed by residents of the islands and assisted for a time by research funds donated by the Massachusetts Institute of Technology.

The work of the observatory, organized and directed to the present time by Dr. T. A. Jaggar, Jr., has already resulted in a most important contribution of fundamental data on the phenomena of volcanism, greater, perhaps, than has been obtained by the study of any other volcano. The value of systematic and continuous observation and permanent record has been clearly established. For example, it is only by such sustained and complete records that the facts of periodicity can be determined and an ultimate knowledge of the influences controlling such periodicity may be gained.

The Committee believes that the Weather Bureau can most effectively contribute to the advancement of the sciences of volcanology and seismology, under the present small appropriation, by maintaining the Kilauea Observatory as the major undertaking, with such extension of the work in lines to be suggested, as may be found practicable. The observatory should be regarded, however, as the chief base for researches

and observations on all active phases of Hawaiian volcanism, and not for Kilauea alone.

The work at Kilauea involves on the one hand the observation and record of phenomena and on the other certain investigations by the observatory staff or by specialists whose assistance it is practicable to secure. The researches as to gases associated with the magma at eruption and the development of heat through chemical reactions occurring under decrease of pressure and other conditions of approach to the surface are of greatest importance. The results of coöperation in these studies with investigators from the Geophysical Laboratory of the Carnegie Institution of Washington, already secured, illustrate the desirability of continuing such collaboration and promoting similar work in other lines. We understand this to be the commendable policy of the Director of the Observatory.

It is known that there have been marked differences in the chemical composition of the lavas erupted at various times in several of the Hawaiian volcanoes. It is very desirable to know the chemical composition of the magma exhibiting the observed characteristics of eruption and to note the relation of this composition to a great variety of textural and mineral features of the rocks developed on consolidation of the lava. It will be fortunate if the assistance of specialists capable of conducting such researches can be secured by coöperation or otherwise.

Mauna Loa, the giant volcano adjacent to Kilauea, presents many important problems for investigation, both individual and in relation to Kilauea. It represents a different stage in the development of a basaltic volcano. Its eruptions are on a larger scale than those of Kilauea and under somewhat different conditions. It is desirable to compare its phenomena with those of Kilauea, and to determine the genetic and existing connections of these two neighboring vents of similar magmas.

The difficulties of access to the summit crater of Mauna Loa and to the main rift or fault zones on which modern eruptions are most frequent make the investigations highly difficult or impossible at this time. The Committee recommends that special attention be given to the development of trails, the establishment of shelters and camps, and the provision of proper equipment, which will facilitate access to the most important points for observation. It is desirable to establish a systematic investigation of Mauna Loa as soon as possible. It will be impracticable, naturally, to subject this enormous volcano to such constant observation as is feasible at the comparatively diminutive Kilauea, but adequate preparation will permit the securing of very important supplementary or confirmatory data from study of the short-lived but often extensive eruptions of Mauna Loa.

It is to be hoped that this work may be promoted through coöperation of the National Parks Bureau, the Hawaiian Volcano Research Association and other agencies interested in the study of Mauna Loa.

Besides the study of the active volcanoes it is recommended that the Weather Bureau should include in its field of observation all minor phenomena, such as fumaroles, steam vents, hot springs, local seismic shocks, etc., which indicate either the dying out or renewal of volcanic action at other places. A complete record of such activities in all islands of the Hawaiian group should be kept and observations made from time to time. Thus it is reported that fumaroles exist on the southern slopes of Haleakala, the great volcano of eastern Maui, at points not readily accessible. The evidences of relatively very recent eruptions within the crater of Haleakala and the existence of these fumaroles show that the volcanic fires cannot be assumed to be quite extinct, and may possibly flare up at any time. Facilities should be provided for visiting all places where traces of subterranean heat are found.

Seismologic work at Kilauea, or in the immediate vicinity of any active volcano, is mainly an adjunct to the study of that volcano, and it is a part of the work deserving of careful attention. It will also throw light on the nature of so-called "volcanic earthquakes." By adequate instrumental record of shocks originating in the volcanic field it is certain that valuable information of increasing or declining activity may be obtained which will be an important factor in forecasting future eruptions. This would be of special importance as regards eruptions of Mauna Loa. It will be necessary, however, to place seismographs adapted to this work at several places about the mountain in order to locate approximately the point at which an outbreak may be anticipated. If a relatively cheap instrument which can be attended to by a volunteer observer becomes available, this observation of local shocks originating beneath Mauna Loa should be provided for.

The seismographs hitherto in use at the Kilauea Observatory are not of the best models obtainable at the present time. Some of them have been loaned by private institutions or individuals. It is, of course, highly desirable that the observatory should be equipped with its own instruments, of types best suited to the purpose.

The Kilauea Observatory is, manifestly, not the most favorable site for seismometers designed to record earth tremors originating in other parts of the Hawaiian Islands or at still more distant sources. For such instruments an installation at the island of Oahu would be much more suitable. If a study of the seismic disturbances of the Hawaiian group as a whole is to be carried out, it would be necessary to establish secondary stations with appropriate instruments, at selected points on other islands of the group.

III. General Conditions Affecting Future Direction of Work by the Weather Bureau.—It was pointed out in Part I of this report that the advancement of volcanology and seismology, especially in the fundamentally important matter of accurate observation of phenomena, would

be greatly promoted by systematic coöperation of scientific men of all parts of the world, working at the presumably widely scattered centres of either volcanic or earthquake activity which may be of special importance at any given time. Efforts to establish such coöperative researches in various earth sciences are now being made. The field to be covered is so great that in some places laboratories or observatories are likely to be established where work in several directions can be carried on. As an instance may be cited the observatory at Apia, in Samoa, founded by the Göttingen Academy of Sciences, where data of much value in the fields of seismology, meteorology, terrestrial magnetism, atmospheric electricity and tidal movements have been obtained.

While this committee believes that the Weather Bureau should not undertake to organize an extensive scheme of investigation in volcanology, it is felt that it may well conduct the work of the Kilauea Observatory for the present. It may be pointed out in this connection that meteorological observations of much value to the Weather Bureau are made under the auspices of many private institutions and individuals, as a contribution to the work of the Bureau.

In the course of the development of scientific research it may well be that some large organization will be formed, devoted to the prosecution of researches in volcanology in the United States or in the Pacific basin, which could take over the Kilauea Observatory, to the benefit of science. The desirability of such a transfer may be considered if and when a permanent organization of this kind is formed.

Under existing conditions it appears evident that hearty coöperation between all Governmental Bureaus conducting scientific work in Hawaii will be of great mutual benefit. The Committee ventures to refer directly to the mutual interest of the Weather Bureau and the National Parks Administration in making both Mauna Loa and Haleakala accessible, by constructing trails and shelter or camp accommodations, and in securing good topographic maps by the U. S. Geological Survey, of Kilauea and the two volcanoes just mentioned.

A geological survey of the whole Hawaiian group under either national or territorial auspices would be of great value to the volcanological work of the Weather Bureau. A well-considered coördination of the work of the Kilauea Observatory and of a geological survey should, of course, be made.

The Hawaiian Volcanic Research Association includes a number of generous, broad-minded men who retain an active interest in volcanological studies and it is in a position to take a helpful place in any coöperative scheme. Two other organizations in Honolulu, while not primarily interested in seismological and volcanological research, are devoting their resources largely to the promotion of science in the central Pacific region. One of these, the Bishop Museum, has expressed a desire, through its

Acting Director, to take part in any scientific undertaking which comes within the scope of its deed of trust, and the other, the University of Hawaii, possesses good laboratories and an increasingly strong scientific faculty.

The importance of world-wide correlation of plans for the advancement of the earth sciences has been referred to repeatedly in the course of this discussion. In closing it seems appropriate to call the attention of the Secretary of Agriculture to the developments now in progress aiming to secure the coöperation of agencies in many countries in promoting researches in meteorology, seismology, and volcanology, as well as in various sciences.

During the late war the National Academy of Sciences, at the request of President Wilson, organized the National Research Council to assist in coördinating and developing the research facilities of the United States, first as a measure of national defense and later as an aid in prosecuting the war. The success of this advisory and coöperative body has led to its perpetuation by the Academy, as directed by the President in an executive order of May 11, 1918.

The benefits of similar organization in other countries and of coöperation between the research agencies of different countries have been so fully recognized that an International Research Council has been formed by representatives of central bodies corresponding to the National Research Council, in several of the allied and associated countries.

One of the principal fields of effort for this International Research Council is to secure the formation under its auspices and with desirable unity and coördination of a number of international associations devoted to particular fields of science. These new organizations replace, in some instances, older ones whose operations were suspended during the war and cannot be revived to advantage under existing conditions.

Among these new bodies of international scope is the International Geophysical Union, devoted to a harmonious development of the earth sciences of physical aspect, dealing with many over-lapping problems. This Union has sections of (a) Geodesy; (b) Seismology; (c) Meteorology; (d) Terrestrial Magnetism and Electricity; (e) Physical Oceanography; (f) Volcanology. (A section of Geochemistry has been added since the submission of this Report.) As a part of the plan there will be organized in each country participating in the International Research Council a branch of the Union with sections corresponding to those named. Thus, in the United States, the American Geophysical Union has already been formed, in connection with the National Research Council. Professor Marvin is the Chairman of the Section of Meteorology. The membership of the various sections embraces a considerable number of leading investigators of the country in the special fields involved.

It is therefore possible at the present time to bring projects for the de-

velopment of seismologic and volcanologic research directly before both national and international bodies qualified to furnish advice and promote a broad coöperation of great value.

Yours respectfully,

WHITMAN CROSS, *Chairman*,

WILLIAM BOWIE,

ARTHUR L. DAY,

H. E. GREGORY,

H. FIELDING REID.

ERRATA

P. 215. For $v = \frac{9. \epsilon. E. D}{4\pi. \eta. l}$ read $v = \frac{q. \epsilon. E. D}{4\pi. \eta. l}$.

P. 268. In theorem II for "but $B_{\nu\lambda} \equiv 0$ " read "but $B_{\nu\lambda}$ not $\equiv 0$ "; and in theorem IV for "or $0 \frac{+}{+}$ " read "or not $\equiv 0$ ".

P. 416. For the denominator of (1) read $2^a p^b$ where $a = \frac{1}{2} p^{n-1} (p-1)^2$, $b = \frac{1}{2} n p^{n-2} (p-1)^2 - 1$, and on p. 417 read p^b for the denominator of the second fraction and 2^a for the left side of the next formula.